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Archiving and Management of Power Systems Data for Real-Time Performance Monitoring Platform

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1 PREFACE

The intent of this document is to lay a general foundation for effective and systematic management of data and information for real-time performance monitoring of large power systems. It does so through a consideration of overall data applications, and by drawing upon industry experience in the operation of wide area measurement systems.

The treatment of these topics is intendedly broad, and digressions into underlying details have been avoided so far as possible. The reader may note, for example, that the distinction between data and information is not absolute – e.g., the information produced by one process may serve as raw input for some later process at higher level. There is also some ambivalence in terms such as "archive" and "real time." Their meaning was fairly clear for analog data streams, but it is much less so for high performance digital systems. Such terminology should be interpreted according to context, and with support from the various cited references. A Glossary is provided in Section 9 as a guide to acronyms.

2 INTRODUCTION

Over the past century, power systems have advanced from single generating plants to highly interconnected grids spanning thousands of miles. These modern power systems play an essential role in our society by providing a highly reliable energy source. However, they occasionally experience massive breakups affecting large residential and industrial areas [1,2]. The lessons learned from such breakups are instructive but costly.

Assuring power system reliability has been a major objective since the beginning of the industry. Today's power engineers are especially concerned about power system reliability for a number of reasons. Economy growth demands more power from the electric infrastructure, and increases the stress upon aging facilities. Deregulation encourages operating the system in ways for which it was not originally designed, and that operation becomes increasingly variable and difficult to predict. Grid managers find it increasingly difficult to determine and observe the limits of safe operation.

The US Department of Energy (**DOE**) has been addressing such matters through the Transmission Reliability Program (**TRP**). A major vehicle for this is the (Consortium for Electric Reliability Technology Solutions (**CERTS**), which extends and broadens the earlier Wide Area Measurement System (**WAMS)** Projects [3].

A "roadmap" for CERTS research into real-time grid reliability management is shown in Figure 1. The tools discussed in this report are part of research area A, Real-Time Performance Management (**RTPM**). This function requires extensive and timely data, collected across the power grid and at different levels, to determine the operating status and operating trend of the grid.

Modern power systems now contain many instruments and recording devices, and vast amounts of data can be acquired. Even though data coverage is not always satisfactory, the major challenge has shifted from data acquisition to effective data utilization. Major factors in this include timely integration of multi-source data, extraction and distribution of useful information, and assuring general integrity of the overall information system [4,5]. The processes and technologies for satisfying these needs are key elements of the CERTS R&D roadmap.

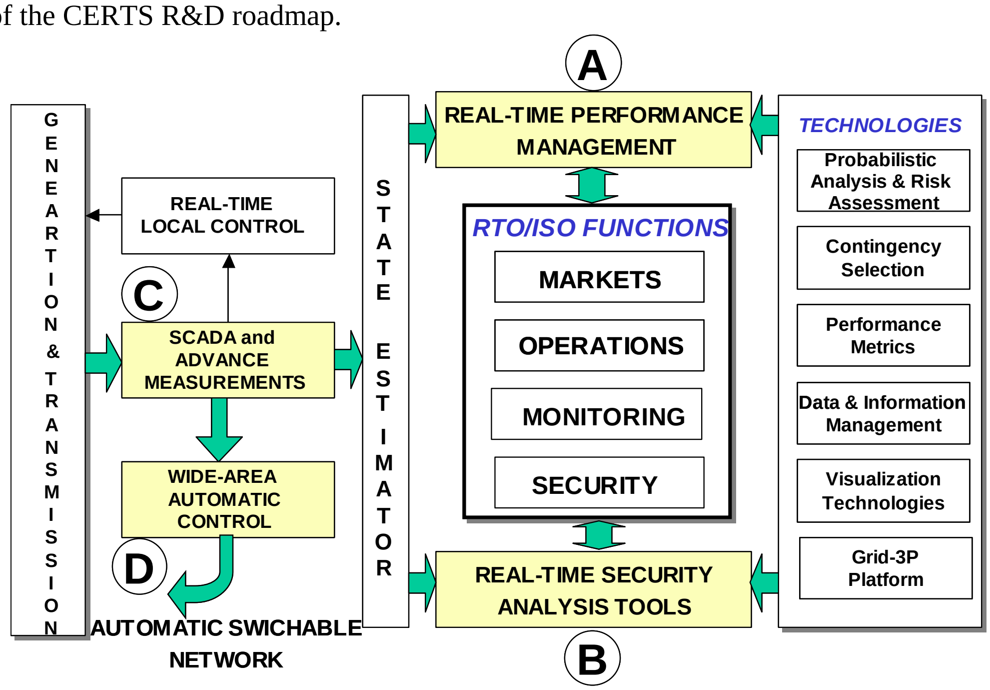

Figure 1 Secure and reliable power system operation (CERTS R&D roadmap)

3 BACKGROUND[1]

Well integrated data and information are essential to the management of large power systems. The primary "backbone" for this during real time operation is the Supervisory Control and Data Acquisition system, which is often just called SCADA.

Most SCADA systems have evolved over a period of decades, and are shaped to the needs of a specific utility. Reliability events such as the system breakups in 1996 [1,6] have demonstrated the need to share such data more widely. To this end, the North American Electric Reliability Council has fostered the Reliability Information Network (RIN) [7], and has networked individual SCADA systems into its NERCNet data center at Princeton, NJ [8].

Many aspects of power system behavior are not visible to conventional SCADA technologies. Chief among these are fast dynamic activity that cannot be captured at the slow data rates employed by standard SCADA, and small but meaningful equipment interactions that are below its numerical resolution [9]. To fill this gap, several decades ago the Bonneville Power Administration (BPA) joined with other utilities in the western interconnection to develop and deploy what was then called the Western System Dynamic Information Network (**WesDINet**). High quality dynamic information was seen as essential to assets management visions, such as the Intelligent Energy System (**IES**) and EPRI's Flexible AC Transmission System (**FACTS**).

In the early 1990's the DOE performed an assessment of longer-term research and development needs for the future electric power system. BPA and other Federal utilities conveyed a strong concern that market forces attending market restructuring were a major disincentive to what are now called ***reliability investments***, and that ***reliability assets*** were undergoing a protracted and serious decline. A considerably enhanced ***information infrastructure***, defined broadly to include human resources and collaborative procedures, was seen as the most immediate critical need for improving both reliability and assets management. Technology aspects of WesDINet were given support under the DOE's Wide Area Measurements (**WAMS**) Project [3]. *WAMS* has since become a generic term, and WAMS networks are fast evolving into a high quality adjunct or extension to SCADA facilities.

Two large WAMS systems are operating in the NERC area [10,11]. In the western interconnection, the "WECC WAMS" continuously acquires some 2000 signals at rates of 20-30 samples per second (sps). Its primary backbone is formed of 60 phasor measurement units (PMUs), of which most are linked into one or more of seven distinct synchronized phasor measurement (SPM) networks. All of these networks are based upon BPA's phasor data concentrator (PDC) [12]. In the eastern interconnection, "WAMS east" contains similar technologies but on a smaller scale. These are rapidly expanding under the Eastern Interconnection Phasor Project (EIPP) [13]. The DOE is fostering a very active collaboration between CERTS and the earlier WAMS participants in the deployment and use of both WAMS systems.

Even though data coverage is not always satisfactory, the major challenge in the WAMS effort has shifted from data acquisition to effective data utilization. As anticipated in [3] and [4], WAMS is maturing into a dynamic information network, and it is merging into a broader information system for which SCADA remains the primary platform. Phase angle data have become a routine SCADA element at some utilities, and technology distributed with BPA's PDCs allows all utility staff to view real time displays of dynamic activity in both the time domain and the frequency domain.

Another salient example of integrated data utilization is the Grid-3P (Grid Real-time Performance Monitoring and Prediction Platform) system that CERTS has developed and demonstrated For NERCNet. [14]. Further details of Grid-3P are provided later in this document.

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[1] Some materials in this section are taken from cited WAMS references.

The data needed to manage a modern power system extends well beyond WAMS and SCADA. Prompt access to market data is critical to some aspects of grid management, and detailed logging of market transactions is essential. And, at the other end of the time scale, long term management of the grid may draw upon reports or operational data that are days to decades old. Past events on the system often contain useful information concerning more recent events, or about future system behavior. In extreme cases it may be highly desirable to "browse" the collective knowledge of an entire power system on a given subject, without knowing where promising sources are located or if they even exist [4]. Modern information technology makes this entirely feasible. The resources critical to the task are systematic access to the overall data base, plus a suitably "intelligent" search engine.

The data from which information must be extracted takes on many forms, and it must be available for processing in many different time frames. The nature, context, and priority of that processing are not very predictable. For this reason, and because computer storage has become extremely affordable, the prudent strategy is to "record everything and sort it out as needed"—i.e., to maintain a comprehensive archive [15]. There are many practical issues to consider in making this archive reliable, consistent, secure, and available to those who need it. There are also many policy issues to resolve in the balancing of grid management needs against the proprietary rights of data owners.

The balancing of ownership rights against grid management needs has been a driving factor in the deployment, operation, and use of the WECC WAMS. Though WAMS provides just part of the information needed in grid management, WAMS operation in the WECC provides a useful paradigm for management of the collective data base for a large power system. This theme is pursued in the section below.

4 WAMS OPERATION AS A PARADIGM FOR INFORMATION MANAGEMENT[2]

A major WAMS does not emerge overnight -- it evolves over time, building upon existing resources to address additional needs. This implies a mixture of technologies, data sources, functionalities, operators, and data consumers. Some governing realities are the following:

- **System configuration** is strongly influenced by geography, ownership, selected technology, and the technology already in service (legacy systems).
- **Required functionalities** are determined by who must (or must not) see what, when, and in what form.

Overall, the forces at work strongly favor wide area measurement systems that evolve as "networks of networks" through collaborative agreements among many parties.

There are a lot of advantages to this situation. Interleaving networks that have different topologies and different base technologies can make the overall network much more reliable, while broadening the alternatives for value engineering. It also permits utility level networks to be operated and maintained on the basis of ownership. The ability of a utility to retain data until it is no longer sensitive is an important aspect of information sharing in the new power system.

Salient disadvantages to this situation include protracted reliance upon obsolescent or incompatible equipment types, plus various institutional impediments to sharing of costs and information. These are major factors in the deployment, operation, and value of the WAMS infrastructure.

The WECC WAMS is engineered to support the applications shown in Table 1. Some of these applications are necessarily performed on line, in "real time," either within the control center(s) or by

[2] Much of the text in this section is borrowed from reference [5].

supporting staff at other locations. Off line applications may be performed later, or at still other locations. This separation is largely based upon workflow priorities, and/or the length of time that is needed to assemble the relevant data plus the staff resources to process them. The dominant factors in this are data access policies and resource investments, not the performance of available technology.

Essentially all of the Table 1 applications software can be adapted to real time use. The software is designed to process a series of files, and the processing logic for a stream of files that arrive in real time is nearly indistinguishable from the processing logic for a series of files extracted from a fixed archive. WAMS data files can always be thought of as belonging to some archive, though the age of that archive may range from seconds to decades.

Successful use of the WAMS analysis software requires that the data presented to it be *consistent, timely*, and *comprehensive*. These qualities are still lacking in the present generation of WAMS facilities. Salient problems include the following:

A. *inconsistent measurements*, due to differences in instrument logic or synchronization
B. *defective measurements*, due to hardware anomalies or messages lost somewhere in the data system
C. *delayed information*, due to delayed data release, need to repair defective measurements, special requests for unusual data, or difficulty in developing the sequence of events
D. *incomplete information*, due to limited WAMS coverage or defective measurements that cannot be repaired

Synchronized phasor measurement (**SPM**) systems are not entirely free of the technical problems shown above. The merits of synchronized data collection are very clear, however, and the WECC WAMS is evolving toward a full synchronized system measurement (**SSM**) with an extended coverage that will include key generators and major control systems.

The management of WAMS archives is a direct extension of WAMS operation. Good operating practices, like good data, are the key to success. The reader should consult reference [5] for detailed recommendations on WAMS operation, and take note of "calibration & refinement of measurement facilities" in Table 1. Recent examples of this particular activity are shown in references [10] and [16].

The engineering of any large information facility must reflect both the needs to be addressed, and the way the facility will be used. Deployment of fully integrated WAMS facilities is hampered by significant uncertainties in both regards. These reflect unresolved policy issues concerning grid management, access to market sensitive operating data, and the sharing of infrastructure costs [17].

One result of these uncertainties is that the technology needs for management and use of WAMS data must be estimated without full knowledge of the system architecture, or of process timing. Many technology needs are generic to any information system, however, and Figure 2 provides an overview of anticipated technology needs for real-time applications for system monitoring, control, and market analysis. Within this framework the Pacific Northwest National Laboratory (**PNNL**) and the Electrical Power Group (**EPG)** are collaborating in a joint effort under CERTS to refine these requirements and to explore most appropriate hardware and software structures.

Table 1. General applications for WAMS data

• Real time observation of system performance • Early detection of system problems • Real time determination of transmission capacities • Analysis of system behavior, especially major disturbances • Special tests and measurements, for purposes such as - special investigations of system dynamic performance - validation & refinement of planning models - commissioning or re-certification of major control systems - calibration & refinement of measurement facilities • Refinement of planning, operation, and control processes for best use of transmission assets

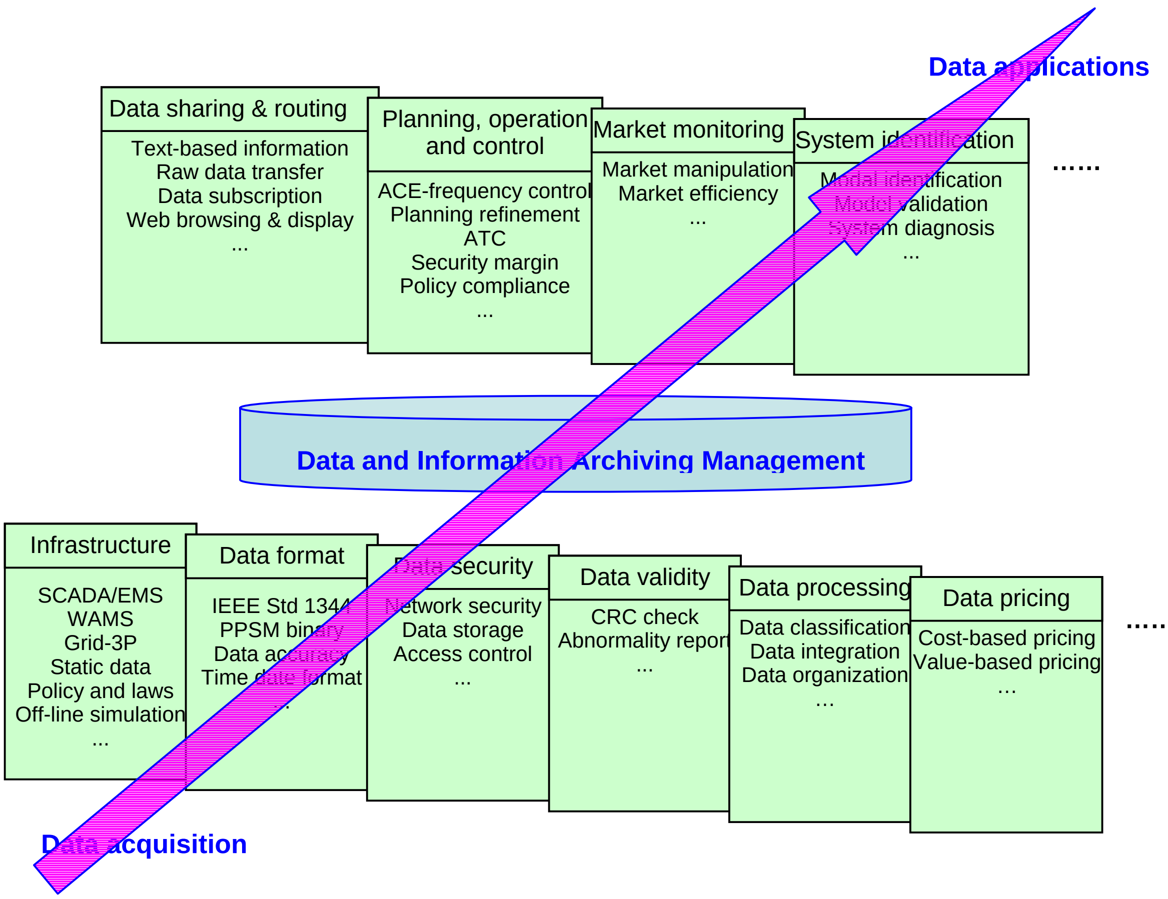

Figure 2 Data and information archiving management

5 DATA ARCHIVING REQUIREMENTS FOR REAL-TIME PERFORMANCE MONITORING APPLICATIONS

Many fundamental organizational and operational changes are happening in the electricity industry. Traditional vertical integrated assets of utilities have been separated, creating not just organizational changes, but also operational challenges to maintain system reliability and efficient competitive markets with fragmented components and different asset's ownership.

Emerging real-time performance management (RTPM) needs and application tools require high levels of data availability, data archiving and better data and information quality because stakeholders non-compliance with performance guides, standards and market rules could translate into electricity supply reliability risks and high economic penalties that will have to be validated and substantiated using easily accessible, accurate and reliable archived data.

End-users experience using some already operational RTPM applications researched, developed and delivered by CERTS indicates the urgent need to improve data archiving strategies and capabilities that warrant:

- Data quality and integrity
- Confidential data-sharing
- Effective data and information integration
- Access and restore times

The above requirements should respond to real-time database growth and end-users with different data needs and skill levels but with real-time interaction requirements.

5.1 CERTS Research Areas for Real-Time Grid Reliability Management and Real-time Performance Monitoring Requirements

The CERTS real-time grid reliability management research roadmap is redrawn below in Figure 3, showing four major areas (A through D) to improve grid reliability management; the tools discussed in this report are part of research area A, Real-Time Performance Management.

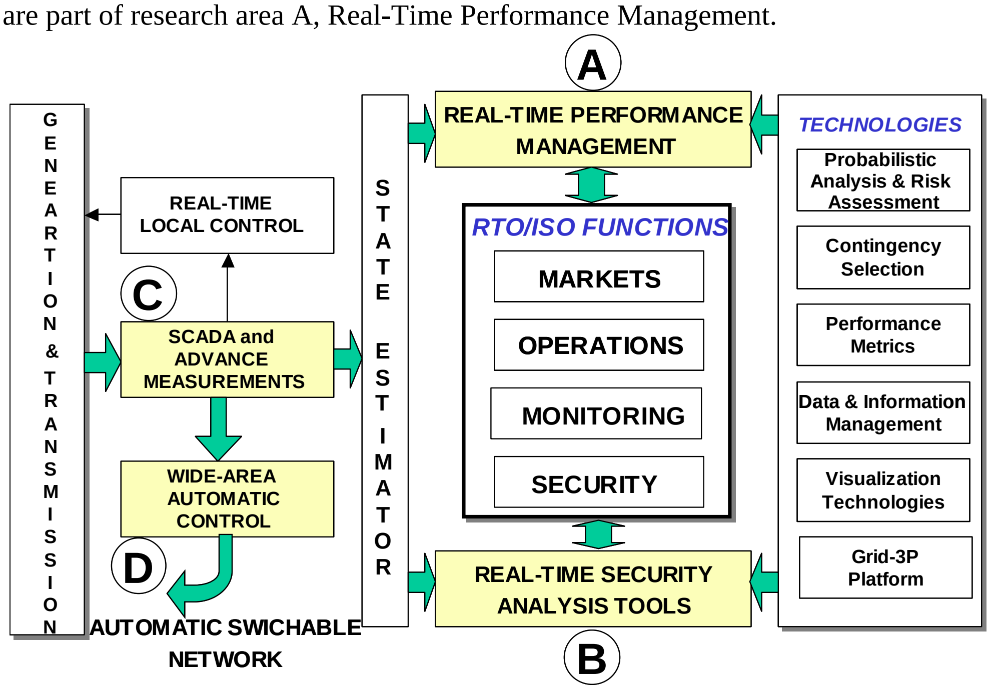

Figure 3 Secure and reliable power system operation (CERTS roadmap)

The direction set by the CERTS Management Steering Committee for the data archiving project is to research, recommend and prototype data archiving capabilities. Systems need to be developed that fulfill the data sizing, quality, response, data-sharing confidentiality, geo-graphic visualization, users with different data needs and skill levels and security and archiving requirements, specifically for the RTPM applications CERTS has already delivered for real-time monitoring operations, and for other RTPM applications CERTS currently has under research, development or field test in its Real-Time Grid Reliability Management research area.

5.2 Real-Time Performance Monitoring (RTPM) Applications

Figure 4 describes in more detail the specific objectives for the metrics, monitoring, analysis and assessment stages of CERTS performance management strategy, and also shows that the CERTS set of RTPM tools discussed in this paper, is fulfilling the monitoring stage, allowing system dispatchers and operators to monitor and track in real-time performance metrics related to reliability parameters such as frequency, voltage and system dynamics.

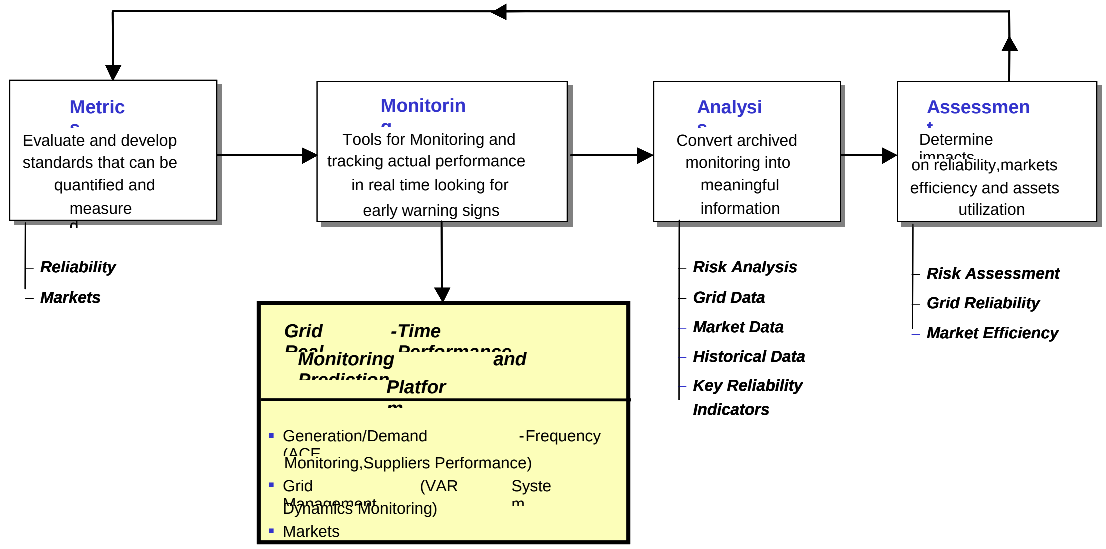

Figure 4 Real-time performance applications in control/monitoring environments

5.3 Example of Typical RTPM Application - ACE-Frequency Real-Time Monitoring for Reliability Coordinators

To illustrate and describe the purpose, architecture and data flow of a typical RTPM application to help understand typical CERTS RTPM application data archiving needs and requirements, Figure 5 shows the overview of the hardware and software for the ACE-Frequency Real-Time Monitoring System. The top right-hand portion shows the three major functional components of the ACE-frequency monitoring application: data collection from the 143 control areas (A), automatic frequency notification and alarms (B), and functional and visual capabilities that allow users to quickly identify the root cause of interconnection frequency abnormalities (C).

The purpose of this real-time system is to automatically notify different operational stakeholders of interconnection frequency abnormalities, and quickly and effectively allow end users to zoom in and systematically search for the root causes of interconnection frequency deviations.

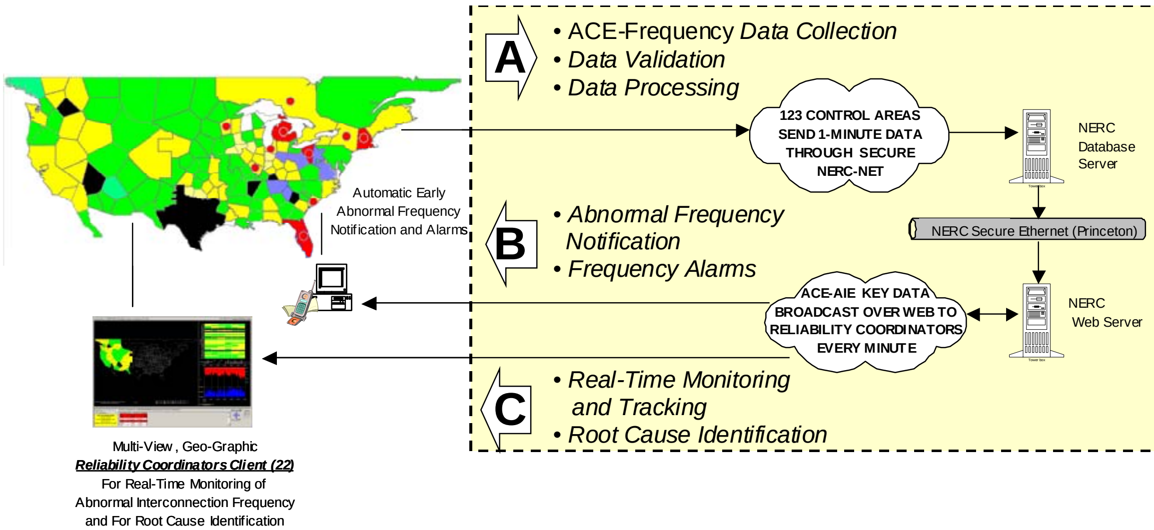

Figure 5 Example of real-time performance monitoring application – ACE-Frequency monitoring

6 DATA ARCHIVING CONCEPTUAL DESIGN FOR REAL-TIME PERFORMANCE MONITORING APPLICATIONS

This section addresses the data archiving system design at the conceptual level. The data archiving system should be generic and modular to ensure its expandability, efficient and cost-effective to facilitate its implementation, and secure and non-vulnerable to protect data from damage and unauthorized access. The concept of enterprise-like systems is adopted for the data archiving system.

6.1 Basic Principles of Data Archiving Design

A systematic and comprehensive data archiving system for power systems will involve every detail in power systems, from data acquisition units to data infrastructure and to how data would be retrieved and used for system analysis. It may also pose changes to existing power systems and large financial investments. Because of this, it is not feasible to create an archiving system "being all things for all people" in the beginning, but we should start small but think long-term. This "start small but think long-term" approach has been successfully used in other industries [18]. The methodology is to have an extensive archiving system design which is generic and modular, efficient and cost-effective, and secure and non-vulnerable, and then to build a small prototype that can grow into a large system with available investments and resources.

6.1.1 Generic and modular

Power systems are continuously evolving with needs and improvements, which has resulted in different types and formats of data measurements existing in current systems. A data archiving system should be able to accept data from such different sources. It should also be generic enough to be compatible with future system evolvement without major modifications. Furthermore, such a data archive system should not be limited to power system physical quantities. Other types of data (e.g. market data) should also be included in archives. So a modular structure should be considered to meet requirements for different data types and formats.

6.1.2 Efficient and cost-effective

NERCNet and WAMS, plus the Internet, have laid a foundation for data collection and transfer. No infrastructure or limited infrastructure should be built for data archive at the first stage. However, the data archive system utilizing NERCNet, WAMS and the Internet should be examined in terms of efficiency and performance.

6.1.3 Secure and non-vulnerable

Data volumes, and information demands, call for distributed storage and management. Also a distributed system is less vulnerable than a centralized system, in the event of data network outage, data device breakdown, or terrorist attack. Data quality control and data access control are also essential to data security in the archiving system.

6.2 Enterprise-like System – a Vision for Data Archiving for RTPM

As shown in Figure 3, the challenge for power engineers is to ensure the reliability, market performance and infrastructure security of a power grid. This will not only require electrical data measurements and information from physical power systems via SCADA systems or WAMS, but also other information, for example, from power market participants, energy resources, government. A comprehensive power system is very much like an enterprise-like system consisting of different sources as shown in Figure 6. Though the current phase targets the information from SCADA and WAMS and markets, the data archiving system should leave space for future development to incorporate information from other sources. On the other hand, the data archiving system should be able to serve data needs from existing and potential power system performance management applications. Examples of these applications are the CERTS ACE-frequency monitoring, supplier-control area performance monitoring for AGC (Automatic Generation Control) and FRR (Frequency Response Reserve), market performance monitoring, and dynamic monitoring using phasor measurements. There are common data needs among all the applications, but each application has its own special data needs as well. Therefore an extension of the data part of a single application will not be sufficient and not generic enough for other applications. Instead, an independent archiving system should be designed and constructed, taking into account all the data needs.

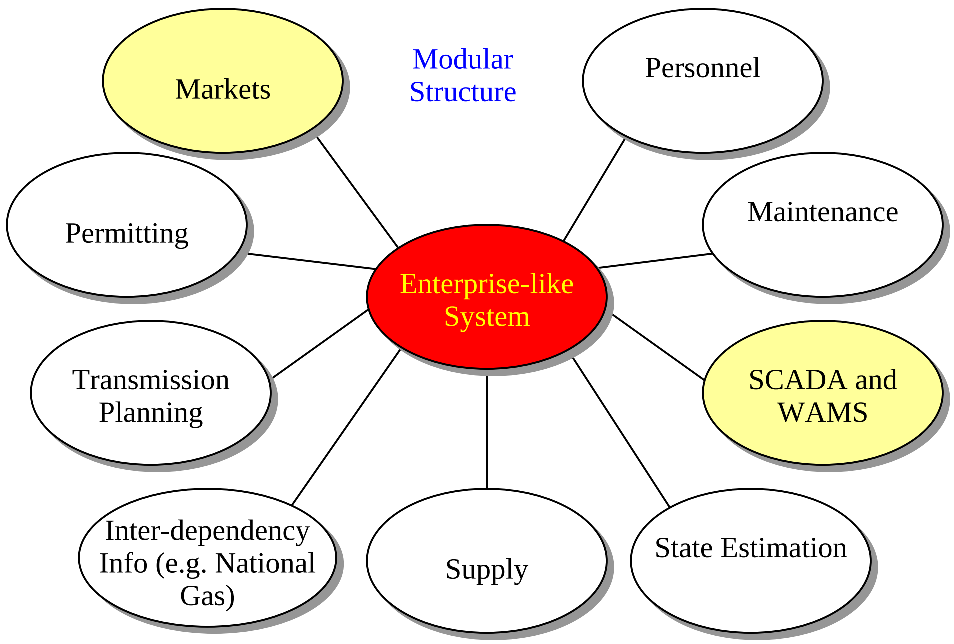

Figure 6 Enterprise-like network with our focus indicated in yellow

The concept of the enterprise-like system has been successfully implemented in many industry areas because its modular structure gives the convenience for each party to "plug in and play" [19]. With this concept applied to the data archiving system, each data source and each data user are relatively independent parts, acquiring, storing and using data as they are doing now. From the perspective of physical entities, this enterprise-like data archiving system is shown in Figure 7. Each entity may have its own data acquisition mechanism and data format.

Major entities involved in the data archiving system are the following:

- **Reliability Organization and Reliability Organization Data Center**: The data search engine and central database (see Section 6.3) reside here. The Reliability Organization is also the authority implementing the data archiving system.

- **Government Authorities**: They may need power grid infrastructure information, major event data, and market overview information to monitor the overall performance of power systems and power markets.

- **Security Coordinators**: They need generation data, load data, topology information, and frequency and voltage data for monitoring system operation, ancillary service, and operation compliance.
- **Utilities**: They include generation, transmission, and distribution operators. They provide data and also they need data for system analysis, scheduling, and control.
- **Control Areas**: They are in charge of regional system operation. Data are needed for load flow inter-area exchange monitoring, frequency monitoring and control, and reserve and service monitoring.
- **Market Participants**: They need data for market analysis, market performance monitoring, and market planning.
- **Energy Companies**: They need to collect information for market activities.
- **Data Marketers**: They provide data for profit. The data archiving system has a limited data processing function. But a data marketer can collect data and add value to it by a post-processing service. Data marketers may also provide a data search engine and maintain its own central database.

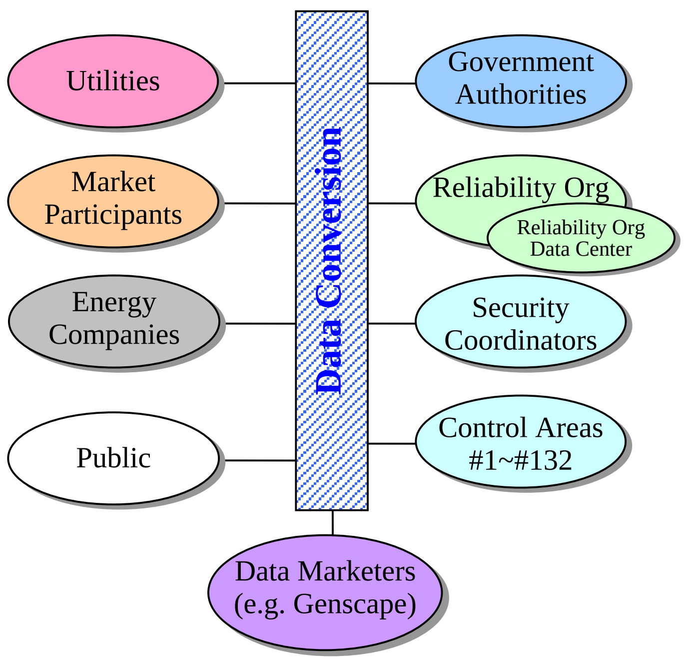

Figure 7 Modular structure and data interface

6.3 Data Archiving Features

The RTPM data archiving system should have the following basic features:

6.3.1 Data conversion

Central to such a RTPM data archiving system is the data conversion, which includes a set of small utilities to convert data between different formats. They are free for use by all interested parties. No single or universal data format is required because data conversion can make the desired format available for data users. Data conversion also provides a standardized naming system for derived signals (e.g. RMS signals derived from phasor measurements) for easy data sorting and management.

6.3.2 Data search engine and central database

Data search engine is a directory-service-like information server. Instead of collecting all the data in the central database, the data center collects information indicating where and what data is available. The data search engine accepts user retrieval requests and routes the requests to proper data sources, which then return the requested data to the data user directly or return the data to the data center and the data center returns the data to the user. The data that has been retrieved and returned to the data center enter the central database and are made available for future requests. Some rules for data requests may be established to facilitate data retrieval. For example, what data should be returned to the data center and enter the central database? Data marketers may provide the functions similar to the data center.

6.3.3 Self-evolving system

The RTPM data archive system is designed as a self-evolving system. Though Figure 7 shows a reliability organization data center, there is no need to move all the data from various data sources to the central database at once. To avoid massive storage requirements at the data center, only selective data should be stored at the data center. Data selection can be done by some arbitrary rules (e.g., select data for a specific event) or by user's data retrieval requests (as stated in 6.3.2). In this way, the data storage at the data center will grow with time. In addition, this central database and the original data source are backup copies of each other.

6.3.4 Data stamp

A data stamp associated with a specific data file may include the following fields: time, key words, associated event, data location, data type, retrieval frequency, data quality flag, data security level, and data description (Figure 8). The fields of time, key words, associated event, data location and data description may help data search. A data file with a low data retrieval frequency for a certain amount of time is indicated as low-usage data and should be removed from the central database at the data center. For example, less than 5 times a year should be considered as low-usage data. Data security level is used for data access control, and data quality flag indicates how good the data are. They are discussed in detail in the next section.

Time	Key words	Event	Data Location	Data Type	Retrieval Frequency	Quality Flag	Security level	Data Description

Figure 8 Data stamp structure

6.3.5 Distributed and modular structure

Data are acquired and initially stored by different parties at different locations. Such data can be "plugged" into the archive system and interdependency between data sources is eliminated.

An example of data retrieval and archive is shown in Figure 9, with the procedure as follows:

1) User initiates the procedure by sending a data request to the data search engine at the reliability organization data center.

2) The data search engine either finds the data in the central database or routes the request to proper data sources. Note that the request can be routed to multiple data sources based on the contents of the request.

3) If the requested data are available in the central database, the data center returns the data to the user.

4) If the requested data are not available in the central database, the request is routed to appropriate data sources, and the data sources return the requested data to the data center. The data sources can also return data to the data user directly. Note that the data center can send out its own data requests to data sources as well.

5) The data center sends the data to the user and also keeps a copy in the central database as archive. The data center also log the data transaction in its database.

6) The user may save the requested data in its own local database.

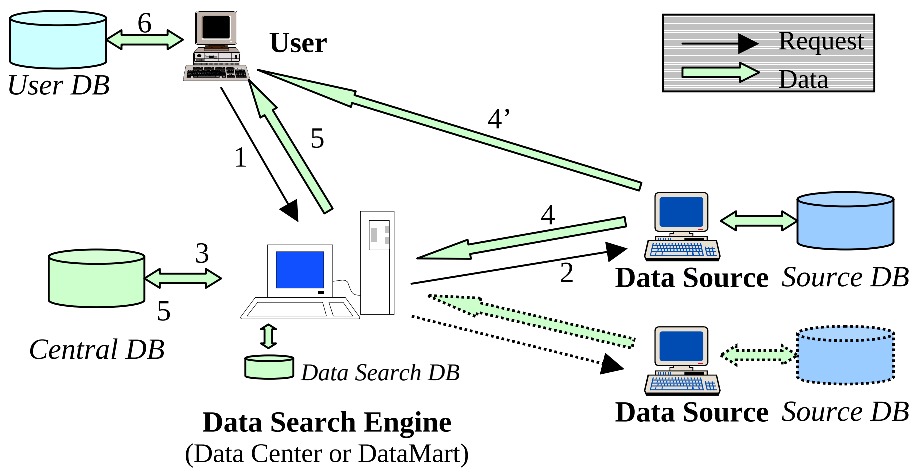

Figure 9 Data retrieval and self-evolving data archive

7 DESIGN ISSUES ASSOCIATED WITH THE TECHNICAL DATA ARCHIVING REQUIREMENTS

Four technical requirements are identified in Section 5 based on the needs of existing and potential power system performance management applications. These requirements are:

- Warranty of data quality and integrity.
- Confidential data sharing.
- Effective data and information integration.
- Adaptability to data requests with different needs and different user levels.

Figure 10 shows the typical data flow in the RTPM data archiving system. Details on how to satisfy the four data requirements are addressed below, respectively.

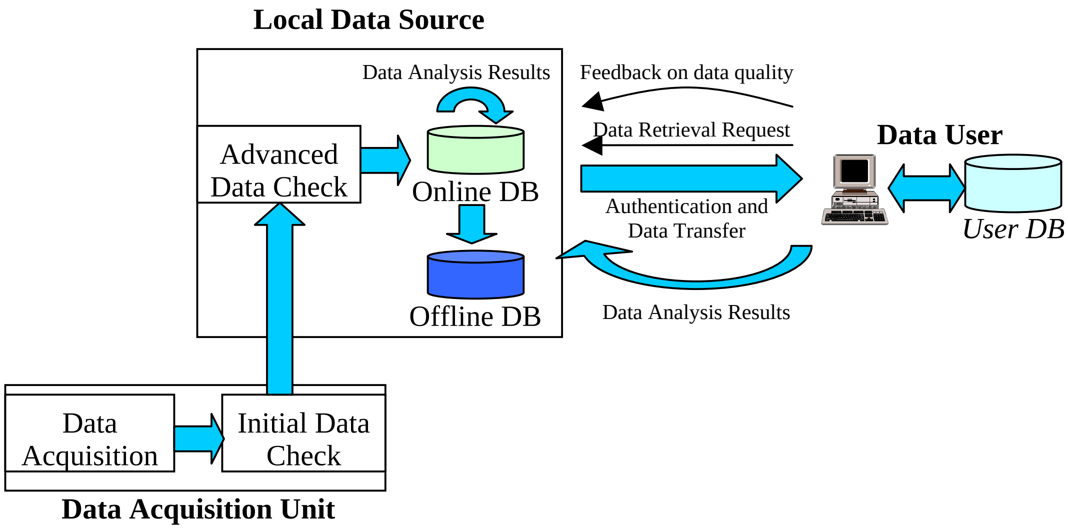

Figure 10 Typical data flow in the data archiving system

7.1 Data Quality, Integrity and Quality Improvements

Wrong data would be worse than no data. So a sufficient level of data quality for the data archive is essential. Data quality control is an important part of the data archiving system. Data quality control can be performed at one or several places as the data are being collected, transmitted and processed. Regardless of where quality control is performed, it is important to mark or "flag" data values that have failed quality control or have been modified by quality control processes. These data quality control flags help database managers and analysts to more accurately interpret and manage the data. A place is reserved in data stamps (Figure 8) for storing the quality flags.

Different data quality levels should be defined based on the quality of the data acquisition units, data checking, user evaluation, and other evaluation methods if available. To avoid overloading data archiving resources, most of the data evaluation methods should be performed at some preliminary level. But detailed data analysis conducted by local data sources or data users can be included in determining data quality. At least the data quality control should provide four data quality levels:

- Suspect or erroneous data – illogical or improbable data values that do not fall within expected ranges or meet established principles or rules.
- Missing data – data values that are missing because of hardware/software malfunction or quality control edits.
- Inaccurate data – data values that are systematically inaccurate (but within the range of plausible values) because of equipment measurement error (e.g., equipment improperly calibrated).
- Credible data – data values that can be used with confidence.

Data quality levels should be constantly updated when new evaluations are conducted. Data quality levels can be expanded to a more detailed degree in practical implementation. For example, a few more levels can be defined to indicate how good the credible data are.

In Figure 10, the initial/advanced data check and user feedback are the major data quality control procedure. Figure 11 further details this quality control procedure for different data categories. Error detection capabilities are a critical component of a data archiving system. Some power system data measurement equipment may have a built-in initial error detection mechanism, which is shown as initial data check in Figure 11. This initial data check gives a quick look at the raw data from a single data acquisition unit to identify some obvious errors, e.g., out-of-range check, rate-of-change check, etc. Initial data check can also include the status and quality evaluation of data acquisition equipment. This equipment evaluation should consider the nominal error, the scheduled out-of-service for routine check, and equipment malfunction, etc.

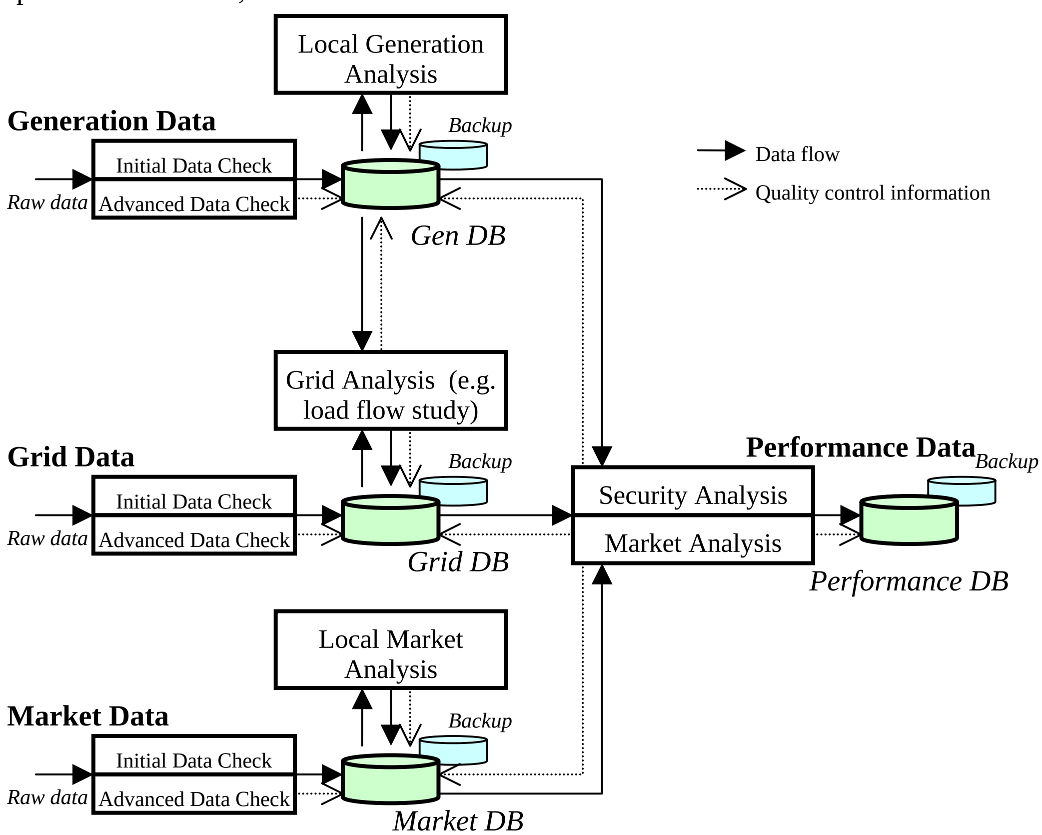

Figure 11 Data quality control procedures

Additional advanced error detection capabilities (advanced data check in Figure 11) may be desirable for data archiving systems. Advanced data check will not only focus on a single data acquisition unit but, more importantly, perform inter-comparison of data from different data units. Rules for advanced data check may be different for different data categories, or even for different data sources in the same categories.

Local and global data analysis, usually performed by data users, provides additional opportunities to determine the quality of data used for the analysis. Each data source can perform its own local data analysis, while security analysis involves data from multiple data sources (Figure 11).

Advanced data check and data analysis can augment the initial routine checking by giving us an idea of the relative utility of data streams, and in essence, tell us "how good" the good data might be. These higher-level checks can also point out deficiencies that are not necessarily detectable within individual data unit checks. The creation of the higher level products also provides the user community with heavily-screened, "pre-chewed" data sets ready for use in high-level scientific research.

Major data quality control rules should include:

- Data acquisition unit nominal error: Usually this information can be located on the name plate or found in the manual or specifications of data recording devices.
- Out-of-service status: Data recording devices may be scheduled for routine check or they are simply out of service because of unscheduled repairs.
- Malfunctions in transducers, communication and storage: Correct recoverable errors via error correction codes, redundant transmittal or other means as deemed necessary or prudent.
- Out-of-range check: Data values should be checked against generating limits, bus voltage limits and other pre-defined data ranges.
- Rate-of-change check: Difference between two consecutive data points are calculated and compared with pre-defined range.
- Inter-comparison for data integrity: For example, frequency measurements can be compared with frequency calculation based on voltage measurements.
- User evaluation through data analysis: Data users may find some not-easy-to-find errors associated with the data they use for data analysis and their feedback should be included in data quality evaluation.
- Data error and deviation analysis: Using data statistics techniques to examine measurements may be necessary for higher data quality. For example, periodically calculate maximum, minimum, mean and standard deviation of data values.

To further ensure data integrity in the archiving system, the following measures may be taken: periodic backup of database, offsite storage of backup data, redundant equipment and enough backup site capability. As mentioned in Section 6.3, this central database and the original data source are backup copies of each other. So there is no need to backup the central database if resource is limited. But each local database still needs to be backed up, because not all the data in a local database have a copy at the central database.

An understanding of the processes that generate, use, and archive operational data are essential to understanding data quality. The root causes of low data quality for real-time control and monitoring systems can be attributed to five primary areas:

- Meters accuracy and data communication problems
- Data collection synchronization
- System downtime problems
- Data retention policy and procedure problems
- Database design problems

Data quality in the context of its utilization for real-time monitoring and operations can best be described for two main purposes: real-time performance monitoring and control, and system modeling. Traditionally, the industry data quality focus was for accuracy and timeless. Now with new organizations requesting additional data and improved data quality, such data and quality need to be assessed from a contextual perspective using multidimensional data quality characteristics. The following two dimensions and corresponding nine characteristics have been identified as closely applicable for the data and data quality requirements for the new emerging applications required for real-time monitoring of compliance with traditional and new reliability and market efficiency metrics and guides:

Intrinsic Data Quality	**Contextual Data Quality**
- Accuracy	- Value-Added
- Consistency	- Redundancy
- Synchronization	- Timeless
	- Accessibility
	- Completeness
	- Security

Within the evolving operational environments of today, data quality requirements are not just good accuracy and timeliness. Depending on the specific application purpose and utilization, one or more from the above nine data quality characteristics could be even more critical and important than the traditional data quality parameters. Real-time control and data centers administrators will need to understand the new data and data quality requirements and establish specific cost-effective plans to expand and support the new data and data quality required by their specific business strategies and end users.

A data quality program is essential for improving data quality within an organization. A good data quality program should:

- Have clear business goals and objectives
- Properly assign responsibilities for data and ensure that those responsible have the tools needed to succeed
- Have an operational plan for improvement that specifies which improvement methods are to be applied to which data
- Establish a program administration

Inherent in a good data quality program is the need to translate data-customer needs into metrics, a team-oriented approach to continuous quality improvement, and benchmarking performance. Many of the classical techniques of statistical quality control, such as Pareto charts and control charts, can be applied to the measurement, tracking, and improvement of data quality.

A comprehensive approach to data quality involves more than "doing the best we can" to provide good data. It requires: a) evaluating the quality of data values and b) evaluating the processes that generate and modify data. As shown in Figure 12, this can be viewed as two parallel activities: (1) performing explicit evaluation of data and (2) establishing organizational control over the processes that generate and modify data.

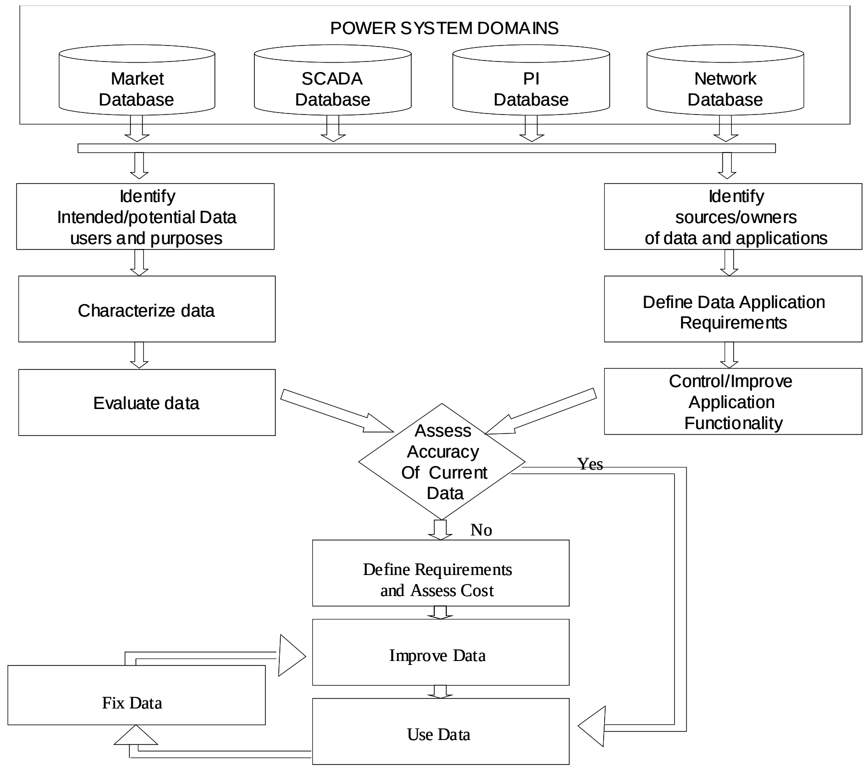

Figure 12 A Framework for Improving Data Quality

Figure 12 is not intended to be a flowchart of the activity of an individual data source producer or application; rather, it attempts to show the parallel processes that should be followed by a team of producers and users to improve the quality of their respective data.

Actions to take on data to improve its quality should be divided into data producer and application. Essentially, producers must warrant the objective accuracy of a database, whereas users must determine its appropriateness for their intended use. The processes that generate, modify, transform, and propagate data should be examined, controlled, and improved whenever possible, to improve the quality of the resulting data.

7.2 Confidential Data Sharing

Because access to power system data could become a factor in the competitive energy market and uncontrolled data access would also pose high vulnerability for power grids, data access should be restricted to authorized personnel. For example, this could become critical because different entities in the data archiving system (Figure 7) may have business conflicts. Safe handling and proper protection of transmitted data in a competitive environment implies that requests for security support in communications need to be satisfied. To enforce data access control, the following security levels should be defined:

- Public data – These data can be accessed by anyone. Examples are electricity price, generation output, load demand, frequency record, etc.
- Business proprietary – These data are related to business operation, for example, generation bidding price. Access to these data should be limited. Unauthorized access could pose damage to business operation and/or profit.
- Utility data – Utility data include operation data, planning data and load forecast data.
- Government/multi-utility planning – This category includes planning data involving multiple utilities. Government or other authority may be involved to coordinate the planning process.
- Intelligence data – This category includes some very sensitive data, including geographical information of power grid, detailed information of nuclear power plants, etc. Unauthorized access to these data could damage homeland security or cause massive loss of power grid.

Both data and users should have their security levels. Data with a certain security level can only be accessed by users with certain security levels. Obviously, users with all the other security levels can access the public data. But the relationship between different security levels is not a simple one-higher-than-another relationship. For example, even the government level may not access all the business proprietary data. Figure 13 shows the compatibility of different security levels. Data security levels are stored in the data stamp (Figure 8). Because different security levels have intersections, one set of data may have more than one security level. For example, data with the levels of both business proprietary and utility can be accessed by users with the levels of either business proprietary or utility, while data with only business proprietary level can only be accessed by users with the same level.

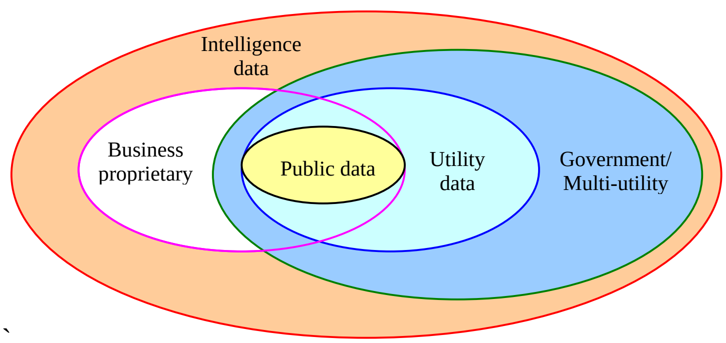

Figure 13 Data security level compatibility

Security levels of data users can be assigned based on established rules (for example, government intelligence agencies should have the highest security level) or mutual agreements (for example, two utilities can share their respective data with each other). Same as data, a single user may have more than one security level as well.

Besides data access, another important issue associated data security is data transfer. The Internet provides a great shortcut to information access. However, it also provides opportunities for unauthorized access. Data protection while data are being transferred should be addressed in the data archiving system design. Some mechanisms of down-selecting signals and substitution of generic names to obscure source information have been in place in the WECC WAMS data management [20][21][22]. Those mechanisms are important means for ensuring data security.

User authentication includes not only the traditional user ID/password pair check, but also security level check. The ICCP (Inter-Control Center Communication Protocol) already implemented a user authentication mechanism. It includes a mechanism for regulating the right to establish a connection and to operate each individual data object. The use of Bilateral Tables, as a representation of the Bilateral Agreement for each remote control center the control center serves, prevents unauthorized access for both associations and operations in objects [23][24]. Encoded data for additional security was also proposed for ICCP [24]. General access to WAMS data is recommended to an Internet-based method because of its low cost and flexibility, but appropriate security restrictions are implemented to ensure that only properly authorized personnel can access the data [4].

The public data can be transferred over the Internet without protective measures. But data with other higher security levels may not be open transferred over the Internet. Virtual Private Networks may be considered to encrypt data before transfer and decrypt after transfer so that the data are opaque to other parties, which are not supposed to access these data [25]. For some very high security requirements, a dedicated connection can be considered to increase the data transfer safety.

Tools should be provided to prevent, detect and recover from unauthorized access to data archives. Also all data access activities should be logged for future reference.

7.3 Effective Data and Information Integration

Over recent years, the number and diversity of monitoring and recording devices in power systems have been greatly increased. Vast quantities of data are generated on an hourly or daily basis, which are supposed to be essential to system monitoring, operations, management and planning. However, it is a big challenge to extract useful information from this data "ocean" without being flooded. The time required, combined with the skills and experience necessary, to retrieve and interpret data are prohibitive and costly. For example, in the WAMS applications, constructing an overview record for WECC (Western Electricity Coordinating Council) main grid behavior draws upon 6 to 10 of the 45 available data sources. Preliminary examination of a significant disturbance generally involves 100 or more of the several thousand signals that are available, with composite record lengths on the order of 20 minutes. Analysis in depth may involve additional signals, plus comparisons against model simulation or previous system events. Therefore, on one hand, a mechanism for data integration should be established. On the other hand, generated information from measured data should be well maintained and retrievable to other data users.

To ensure an effective data and information integration, a progressive procedure may be implemented [26], as shown in Figure 14. The integration level becomes higher as more data and data sources are involved. As the integration increases, data not associated with the function purposes at each integration step are filtered out; therefore, information density is increased. All the raw data and generated data are stored in the local data source archive and/or in the user data archive. Both are made retrievable to other data users who need these data at a later time.

Data acquisition consists of data recording devices, as well as data initial and advanced checks, as shown in Figure 11. This step fills out time, key words, data location, data type and quality flag in the data stamp structure (Figure 8). Data processing identifies events, generates alarm messages and relay protection signals in a SCADA system, and sets the data security level in the data stamp structure (Figure 8). Local data analysis conducts data inter-comparison, local generator performance monitoring, load flow study and market analysis. Data quality is re-evaluated according to the analysis results. Data applications involve measured data and model simulations. Data may come from multiple data sources. Major applications include ACE-frequency monitoring, dynamic security assessment, voltage stability assessment, contingency ranking, post-event analysis, etc. This is a very high level data integration step. Information generated at this step may be sent back to data sources, depending on specific implementation.

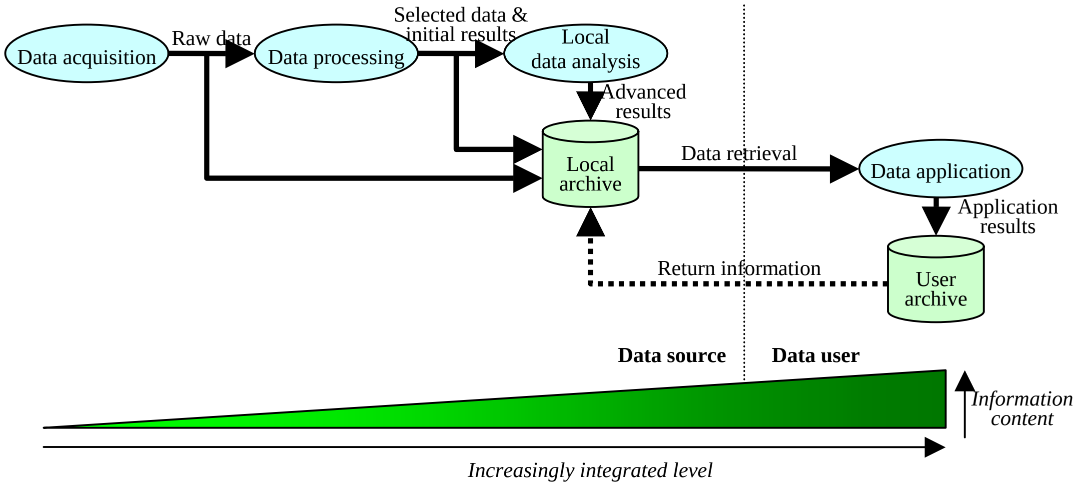

Figure 14 Data and information integration

7.4 Adaptability to Different Data Requests

Given the complexity of power systems, different data applications and data users may pose very different data requests to the data archiving system, which is designed to be generic to satisfy all the requests. Typical data users include system operators and engineers/analysts. System operators monitor and respond to the current or most recent system operating status, so they typically need more current data, for example, within (t – 60 seconds) range. Engineers and analysts usually focus on off-line applications, including system planning, post-event analysis, offline security assessment, market performance analysis. So they are more interested in historical data ranging from current to, say, 5-year-old data. Time for the data archiving system to respond to operators' requests is critical, while engineers/analysts may not need very quick response from the data archive for offline applications. On the other hand, inside a single application, the time requirement may also be different. For example, the ACE-frequency real-time monitoring system can have data requests covering different time windows from current to 30 days (Figure 15) [27].

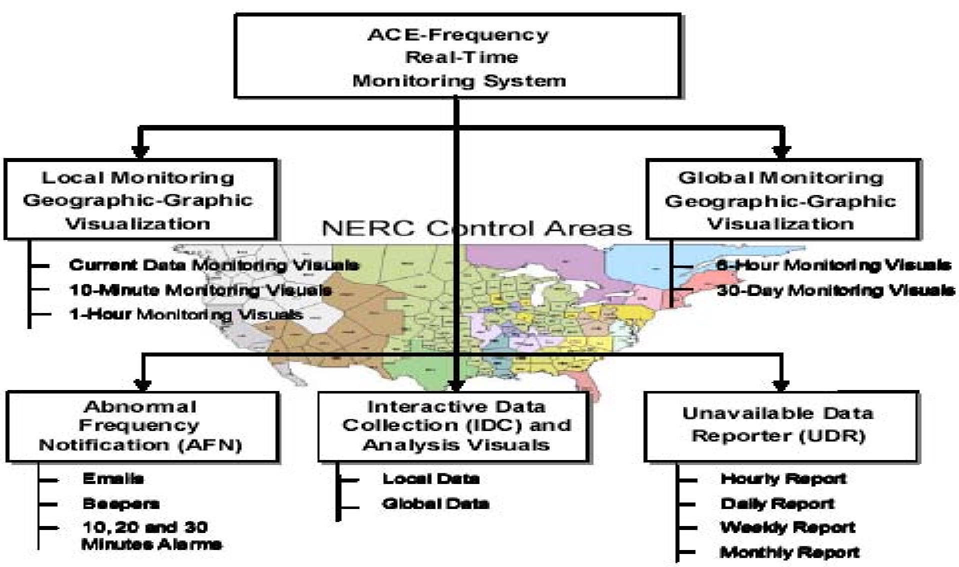

Figure 15 ACE-Frequency real-time monitoring system functional overview

Therefore, to ensure prompt response from the data archiving system, different data requests should be treated differently. But all the data transactions need to be logged for future reference. This should be addressed at two aspects: data storage and data access.

Data storage may have three manners in terms of retrieval speed and cost: online storage, near online storage and offline storage [4].

- Online data storage: Data are stored on rotating mass storage devices, magnetic, magnetic-optical, or optical. It is available in a matter of milliseconds. It can be managed by standard database management systems such as Microsoft SQL server or Oracle.

- Near online data storage: This type of storage typically consists of robotic tape cartridge or optical juke box systems. Retrieval time for this data is in the seconds range. Its biggest drawback is that at the present time it cannot be managed by a database management system. Instead, data on these devices must be reloaded onto online storage media and reincorporated into database management systems. Although reloading may be done under program control, it may still take up to a few minutes.

- Offline data storage: Offline data are typically located on removable magnetic disks, tapes or optical disks stored in data libraries. The retrieval process for offline data consists of locating the unit containing the desired data, hand loading it into a reading device, reloading it onto online storage, and reincorporating it into database management systems. This may take from several minutes to a few hours and is dependent on the availability of operators to locate and load the data.

Stored data will be accessed by an automatic analysis program running at the storage location, such as Archive Walker (sophisticated analysis programs that "walk" through the data) and by users via the Internet. In both cases, the speed with which data can be retrieved is of concern. The most effective data storage schema for this application is to store the older data near at the online level. After a period of time, that data may migrate further to offline storage. This will ensure that the data most likely to be requested will be available immediately, older data will be available in a reasonable period of time, and all data will be retained so that it can be relocated if necessary. Besides the age of data, the retrieval frequency (Figure 8) may also be considered to decide when data should migrate from online to near online and to offline.

It is obvious that online data storage is the best, but it is also the most costly. So online storage is constrained by the associated cost. To meet the requirements of system operations and online applications, all the data should be kept online for at least 30 days. 6 months of near online status are recommended. Offline data should be able to get online within a few hours upon request.

Data networking technology provides various methods to access archived data. Possible options include:

- Dedicated communications lines/channels: Dedicated communication lines are exclusively used for some specific data transfer. They are very expensive and also less flexible. They may only be used for a small amount of data of high sensitivity, security and confidentiality. An alternative is dedicated channels built over the Internet or other existing data networks. These channels remain alive once they are established until users terminate them. So high quality data transfer can be ensured. But they occupy the bandwidth all the time even when they are idle. Some techniques are available to build dedicated channels. The Virtual Private Network technique is an example for such a purpose [25]. These dedicated channels may be used for data that need high reliability,

- ICCP-based NERCNet [8]: NERCNet employs ICCP, interconnecting about 123 control areas across the states. SCADA data can be gathered from control areas over secure connections using NERCNet, XML and SOAP technologies [14]. Current Grid-3P applications are using NERCNet for data exchange.

- WAMS [4,10]: WAMS consists of the WECC phasor data measurement network and the Internet-based data access system. Each PDC unit in the phasor network has the potential for providing real-time data sharing across a broad region of the power system. Presently, most of the directly integrated phasor networks are isolated from one another, so the Internet is employed as the bridge to share data and information between PDCs and from PDCs to other data users. Eastern WAMS is under development. The established data transfer mechanism in WAMS should be used.

- FTP over the Internet: UserID/password authentication must be enforced. Used for less time critical applications.

- Email over the Internet: Data security can be ensured by either the email account security or extra user identification information. This is the slowest method to retrieve data from the archive. Used for less time critical applications.

As aforementioned, there may be a few data applications or functions with different data requests at a single physical point. The choice of data access method should be able to satisfy the most critical data request. For example, the ACE-frequency monitoring application in Figure 15 has a few functions requiring data with different time ranges and retrieval quality. The most critical data request is from the function of local monitoring visualization, where current data are required and high retrieval speed should be guaranteed; therefore, dedicated channels may be used or we can use the existing NERCNet as it is currently used. The general principle is to use existing infrastructure as much as possible.

Also, to avoid the interference between critical and non-critical data retrievals, more than one data access method may be implemented at a single physical location. For example, the real-time ACE-Frequency monitoring and the local data archiving function at the reliability organization data center interfere with each other because these two functions compete for the ICCP-based NERCNet bandwidth. This interference may cause low performance, data loss and function failure to one or both functions. The solution may be to use NERCNet for real-time ACE-Frequency monitoring and use Internet-based method for data archiving.

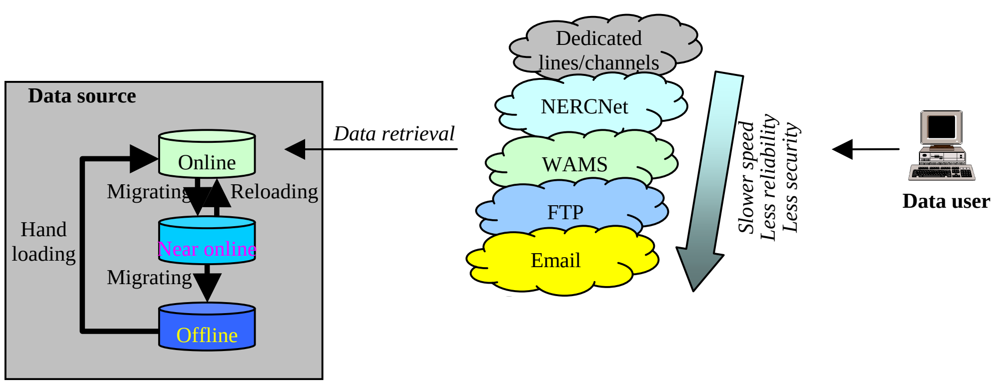

Figure 16 Data storage and data access methods for different data and data requests

8 RECOMMENDED FUTURE TASKS

In line with the requirements presented in this paper, some case studies on the physical architecture for data archiving are presented in the Appendices. Future tasks will focus on the implementation of the data archiving system architecture. Some specific issues to be resolved are listed below.

8.1 Data search engine

This task involves collecting data information, analyzing data requests, routing data requests to data sources and maintaining a data search database. It may be a web-based application. Depending on data request load, a "mirror" site may be built.

8.2 Data conversion utilities

Collect data formats that are currently being used in different data sources and code programs to convert data between different formats. Phasor data format [28] and PPSM binary format [4] are two examples. Other data formats [29] include IEEE C37.111-1991, Electrotek SuperHram, Fluke 41 and 97, etc. NetCDF (Network Common Data Format) [30] and HDF (Hierarchical Data Format) [31] are known as good formats for scientific data storing and sharing. They may be considered as common formats for data stored in the central database.

8.3 Central database at the reliability organization data center

It needs to be decided which data management method should be used for the central data storage: database management or file server management. Self-storing of retrieved data and self-cleaning of low-usage data should be implemented.

8.4 Data archiving performance investigation

Network protocol compatibility is to be examined. Data transfer delay, routing error, data error and other relevant issues should be investigated.

8.5 Data retrieval methods

Different methods can be evaluated, e.g., FTP transfer, web-based HTTP downloading, data subscription, data transfer upon changes, etc. One or a few methods should be implemented based on the evaluation results.

8.6 Data quality control

Data quality can be monitored based on the quality of measurement units, initial data checking (e.g., max-min check, data error check) and user evaluation [32]. Different quality levels can be defined and the data quality flag in the data stamp of a data file stores the data quality level.

8.7 Data communication

Investigate the current problems with ICCP implementations. Examine other communication infrastructures and protocols for communication performance.

9 GLOSSARY OF TERMS

BPA	Bonneville Power Administration
CERTS	Consortium of Electricity Reliability Technology Solutions
DFR	Digital Fault Recorder
DMWG	Disturbance Monitoring Work Group of the WECC
DOE	Department of Energy
DSM	Dynamic System Monitor
EIPP	Eastern Interconnection Phasor Project
EPG	Electric Power Group
EPRI	Electric Power Research Institute
GPS	Global Positioning System
IED	Intelligent Electronic Device
M&VWG	Modeling and Validation Work Group of the WECC
NERC	North American Electric Reliability Council
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
PNNL	Pacific Northwest National Laboratory
PSM	Power System Monitor (primary definition), Power System Measurements (secondary definition)
RTPM	Real-Time Performance Management
SCADA	Supervisory Control and Data Acquisition
TVA	Tennessee Valley Authority
UTC	Coordinated Universal Time (initials order based on French)
WAMS	Wide Area Measurement System
WECC	Western Electricity Coordinating Council
WesDINet	Western System Dynamic Information Network (usually just called the WECC WAMS)
WSCC	Western Systems Coordinating Council (predecessor to WECC)

10 ACKNOWLEDGEMENT

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APPENDIX 1. PHYSICAL DESIGN FOR REAL TIME PERFORMANCE MONITORING SYSTEMS – CASE STUDY I: GRID-3P ARCHITECTURE

A1.1 Grid-3P Overall RTPM Architecture

This architecture was created using a common framework referred to as the Grid Real-Time Performance Monitoring and Prediction Platform (GRID-3P). The Grid-3P is a layered architecture and is the common foundation for many CERTS RTPM tools. As shown in Figure 17, the layers consist of a data layer (relational database and associated time series/mining capability and associated data communications protocols and technologies), an application layer (application specific models and algorithms, e.g., optimization, probabilistic analysis, forecasting, risk assessment, performance metric evaluation, etc.) and the visualization layer (multi-view, multi-layer and geospatial outputs). The visualization layer utilizes synchronized multi-panel displays and it is considered one of the key innovations of the Grid-3P framework.

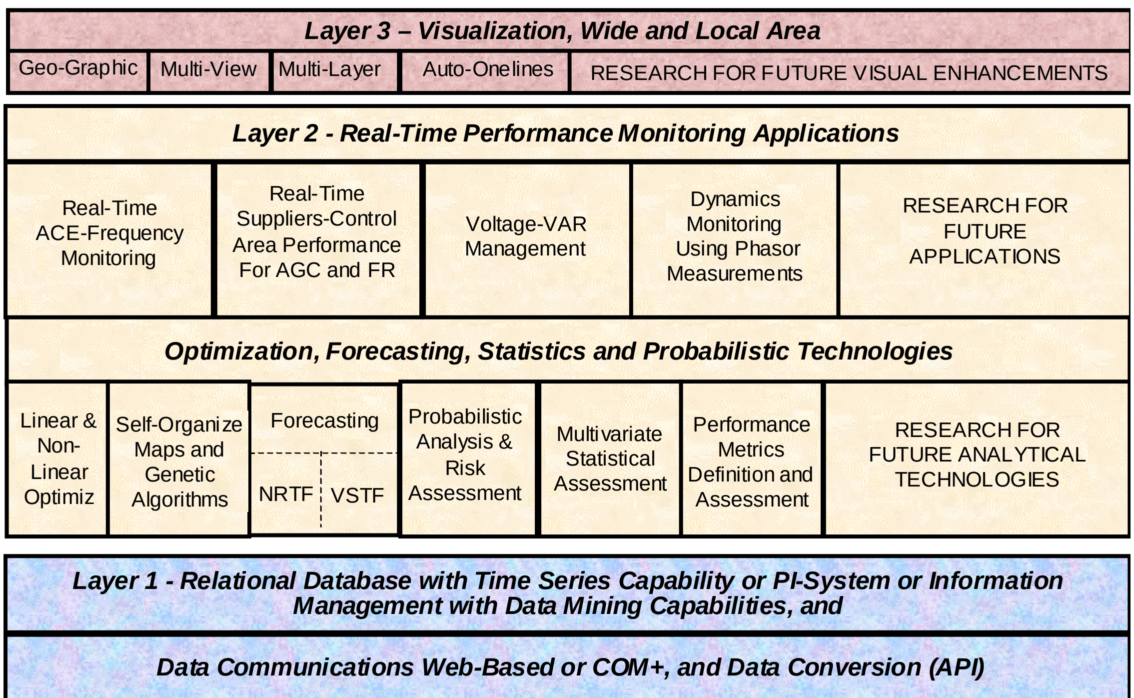

Figure 17 Grid-3P Research and Development Process

Following is a description of the three architectural layers of the Grid-3P infrastructure:

- **Data Input – Layer 1**

RTPM tools use the same data sources used by current SCADA, EMS (Energy Management System) and phasor systems. These tools are not intended to replace SCADA, EMS and phasor systems but instead to complement them by adding real-time performance monitoring capabilities. This layer efficiently collects data from numerous different asset owners, converts to a time series oriented arrangement, and groups within information tables that facilitate an integrated monitoring view for system operators.

- **Functional Calculations and RTPM Applications –Layer 2**

Layer 2 in Figure 17 lists some of the types of functional calculations that can be performed using the input data. Numerical algorithms exist for linear and non-linear optimization, near and very short-term forecasts, in addition to algorithms to determine the risk and probabilities for reaching collapse periods.

These calculations feed into the RTPM applications that monitor key performance indicators of system reliability conditions or market efficiencies.

- **End User Output Visualization - Layer 3**

Layer 3 in Figure 17 lists the characteristics of the local- and wide-area visual displays that present the information from layers 1 through 3. The geographic, multi-layer and multi-view visualization strategy allows operators to quickly assess and act on system conditions.

To deploy the above-mentioned overall architecture, two kinds of architectures are studies for data communications, databases, applications and data clients. The first is a XML-COM based architecture without Internet components for data security reasons, and the second a web-based architecture to have a common and easy to use human-interface.

A1.2 Typical XML-COM Architecture

Figure 18 shows the typical data flow for RTPM applications based on XML-COM. The left side of Figure 18 shows the process, beginning with collection of the required SCADA, market, phasor or information raw data by means of standard software or special programs developed for this purpose. The database is populated using both validated raw input data and data produced using algorithms for sensitivity analysis, calculation of distance from collapse points, remedial action assessment, and risk and probabilistic analysis. The right side of Figure 18 shows the client side of the architecture - the multi-view and geographic visualization, that is the output of each RTPM application.

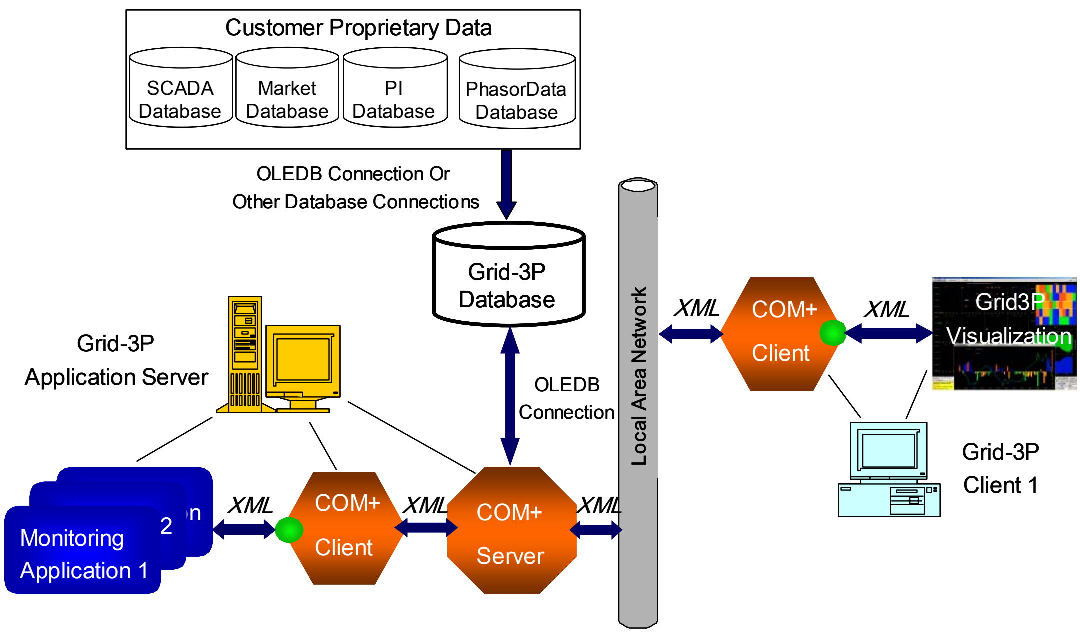

Figure 18 Typical XML-COM Architecture

A1.3 Typical Web Based Architecture

Figure 19 shows the typical data flow for RTPM applications based on XML-COM Web architecture. The left side shows the process beginning with the data collection from different platforms by means of standard software or special data acquisition programs. The right side of Figure 19 shows the web-based client of the architecture. The client visualization is based on geographic multiple-views. For this type of architecture, the requirements and design criteria from Sections 3, 4 and 5 should apply to the Grid-3P database, the Grid-3P client, and the data communication paths shown in Figure 19.

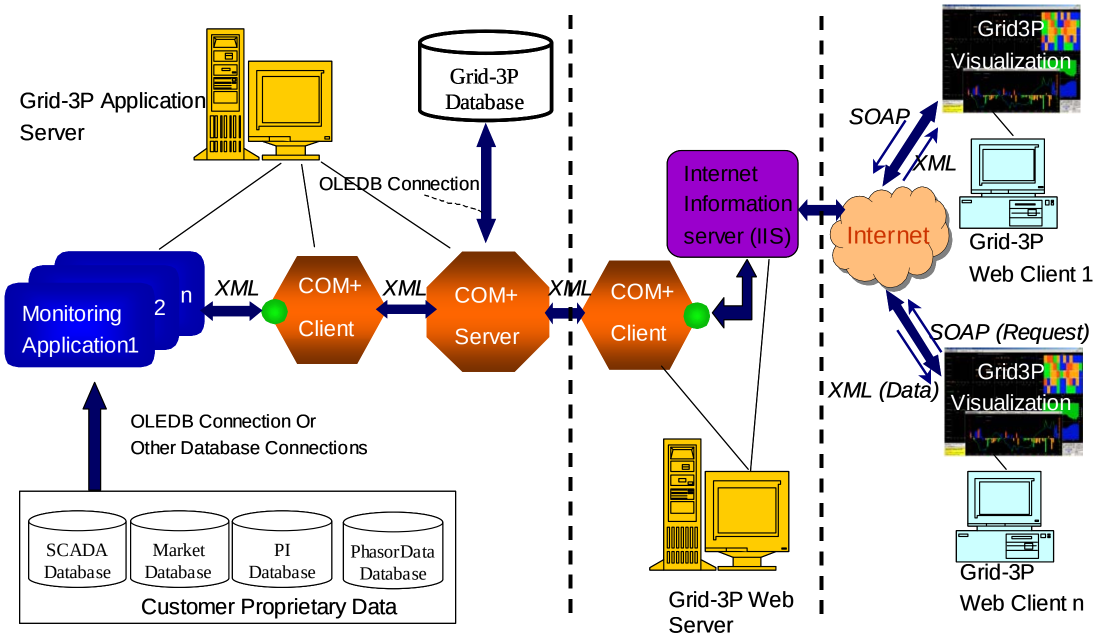

Figure 19 Grid-3P Web-Based Hardware and Software Architecture

APPENDIX 2. PHYSICAL DESIGN FOR REAL TIME PERFORMANCE MONITORING SYSTEMS – CASE STUDY II: WECC WAMS INFORMATION MANAGEMENT ARCHITECTURE

This architecture is developed in the WECC WAMS for integrated information management [4]. In the WECC WAMS, deployment of new monitors – and the proliferation of "intelligent electronic devices" (IED's) in general – are overcoming many of the problems in acquiring raw data. It is clear that this emerging abundance is producing a new generation of challenges in monitor operations. Chief among these challenges are:

- **Timely extraction and routing** of information resident in the data.
- **Selective retention** of valuable data, without inundating data facilities.

A2.1 WECC WAMS Data Management Functions

Research into a generic WAMS Information Management System is designed to deal with such challenges. A key element in this information system is a WAMS Database Manager (DBM). Conceptually and tentatively, functions of the WAMS DBM include the following:

- **Automatic Routing:**
  - Operator alerts
  - Cross triggers to local and remote monitors
  - Event-driven control of local displays
  - Data retention requests to local and remote monitors
- **Servicing of Staff Requests:**
  - Data transfers
  - Special data operations and displays
  - External triggering of local or remote monitors
  - Special log entries
- **Background Directory Operations:**
  - Exchanges among DBM units
  - Integration, annotation, and indexing
  - Posting on EMS, OASIS, WWW
- **Background Data Operations:**
  - Launching and supervision of the Archive Walker
  - Content-based compression and archiving
  - Logging of events and summary feature
- **Utility Functions:**
  - Intelligent browsing of archive materials
  - File merging and compression
  - Hardcopy generation

The monitors involved in this include SCADA, DFR, and other IED units in addition to the usual swing monitors. The DBM will also need access to text-based materials, such as operator logs and detailed technical reports (e.g., on system tests and disturbances).

A2.2 WECC WAMS Information Management System Structure

Figure 20 indicates the expected structure of a WAMS Information Management System plus its connections into the general power system information network. Figure 21 shows a network of measurement units in a topology that is natural to the western power system, and very similar to that of the Interregional Security Network (ISN) [33]. It seems likely that many of the Information Management functionalities will find applications within the resource base needed by the ISN and the WECC Independent System Operators (ISOs) [34].

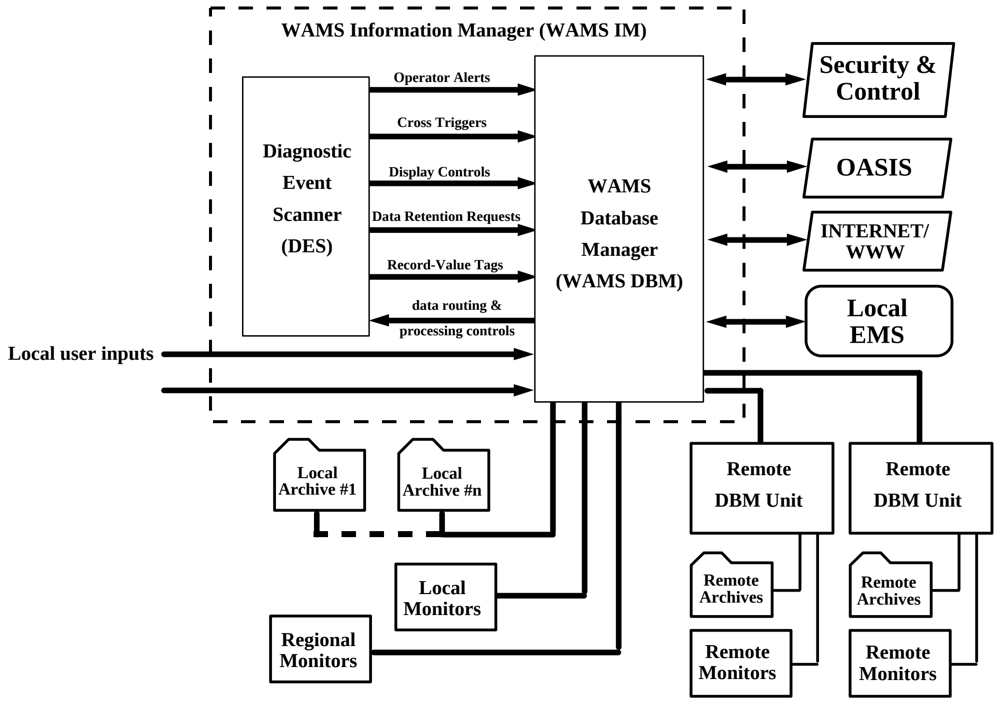

Figure 20 Network connections for the WAMS Information Management System

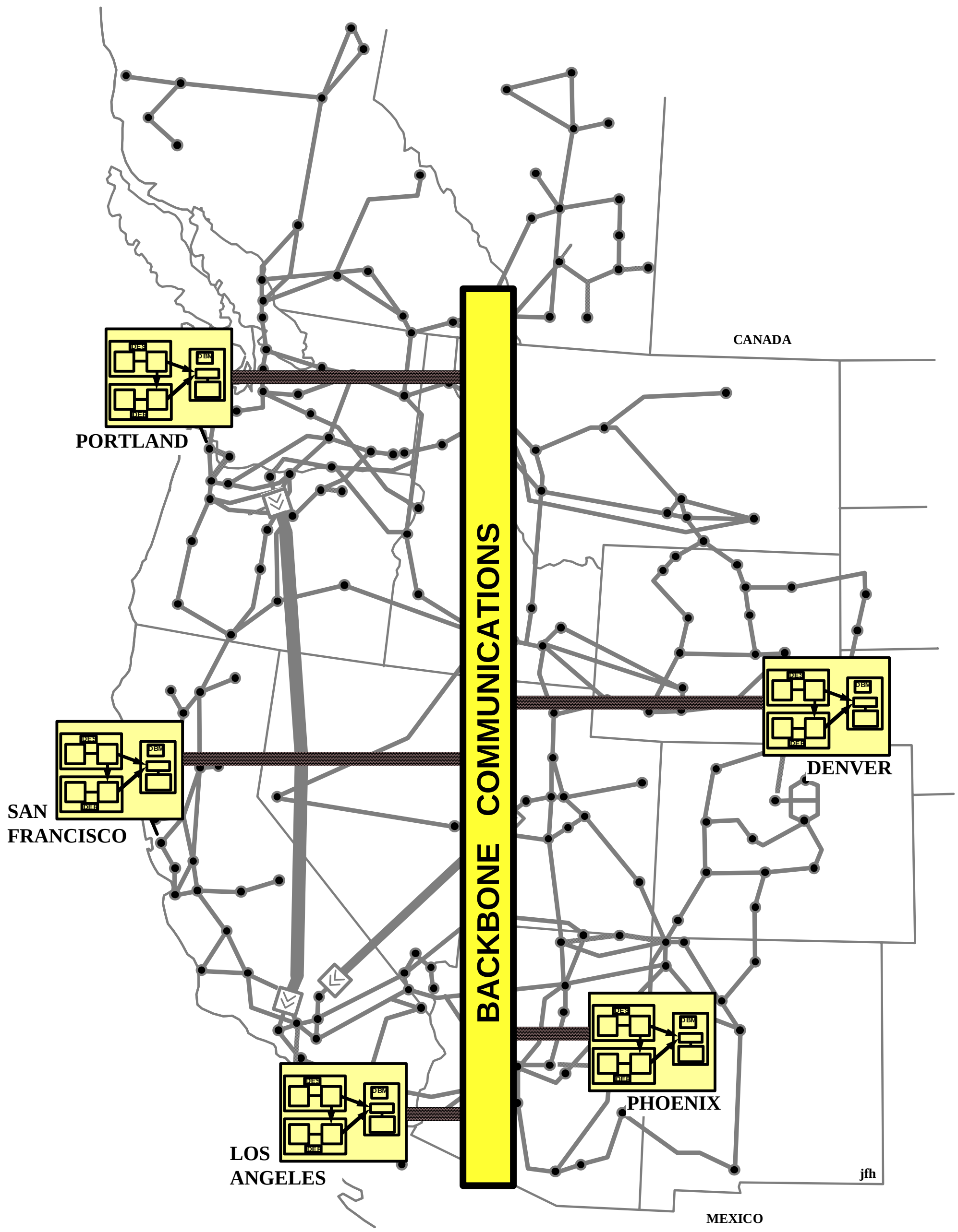

Figure 21 Natural Architecture for the WAMS Information Management Network

Detailed functional requirements for the WAMS Database Manager will necessarily reflect the many forms that the information can take and the many uses to which it may be put. The time frame for applications may range from seconds to weeks or months, and that inputs to the DBM can range from raw operating data to processed information imbedded in technical reports. In extreme cases it may be highly desirable to "browse" the collective knowledge of an entire power system on a given subject, without knowing where promising sources are located or if they even exist. Modern information technology makes this entirely feasible. The resources critical to the task are systematic access to the overall data base, plus a suitably "intelligent" search engine along the lines indicated in Figure 22.

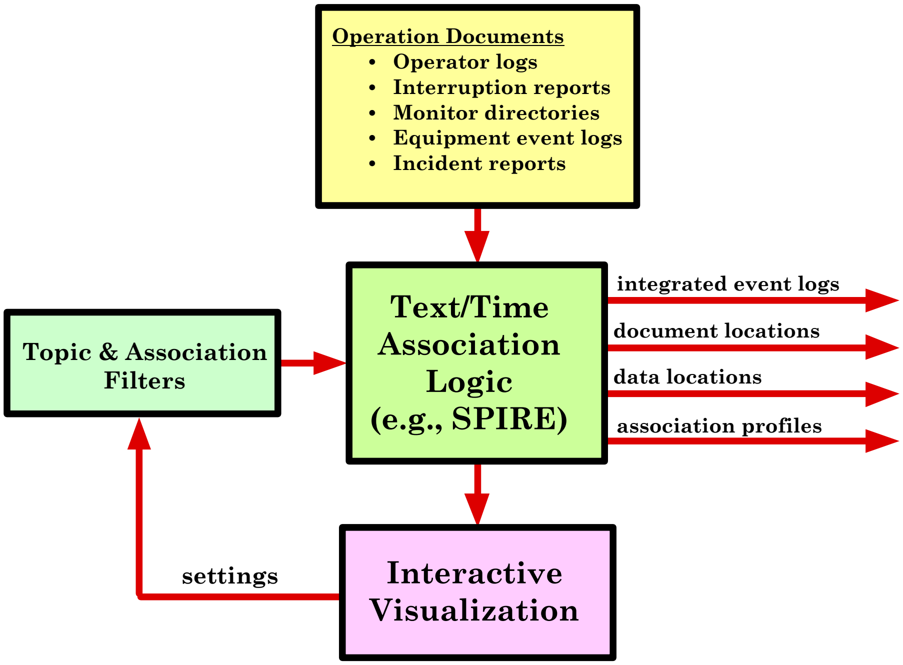

Figure 22 General structure for text/time association of control center operation documents

APPENDIX 3. PHYSICAL DESIGN FOR REAL TIME PERFORMANCE MONITORING SYSTEMS – CASE STUDY III: OSI PI-BASED ARCHITECTURE

The PI system builds a real-time enterprise by providing a real-time information infrastructure that closes the time and information gap between business objectives and actual production floor operations (Figure 23). Data is acquired, routed, processed and displayed simultaneously on desktops, portables and PDAs throughout the enterprise worldwide. This valuable information is stored for decades, yet remains instantly accessible at its original time resolution for automated reporting, trending and analysis, providing insight into your process to realize significant gains across the enterprise. The PI system is your global window into the process. All your employees become knowledgeable workers, making decisions in real-time using real information. Real-time enterprises benefit from faster, more informed decisions that help them better meet production deadlines, customer demand and regulatory standards. Enterprises use real-time intelligence to improve quality control and business processes by using precision reporting, predictive maintenance and more comprehensive planning and analysis. The results are greater efficiencies, motivated employees and a more profitable enterprise overall.

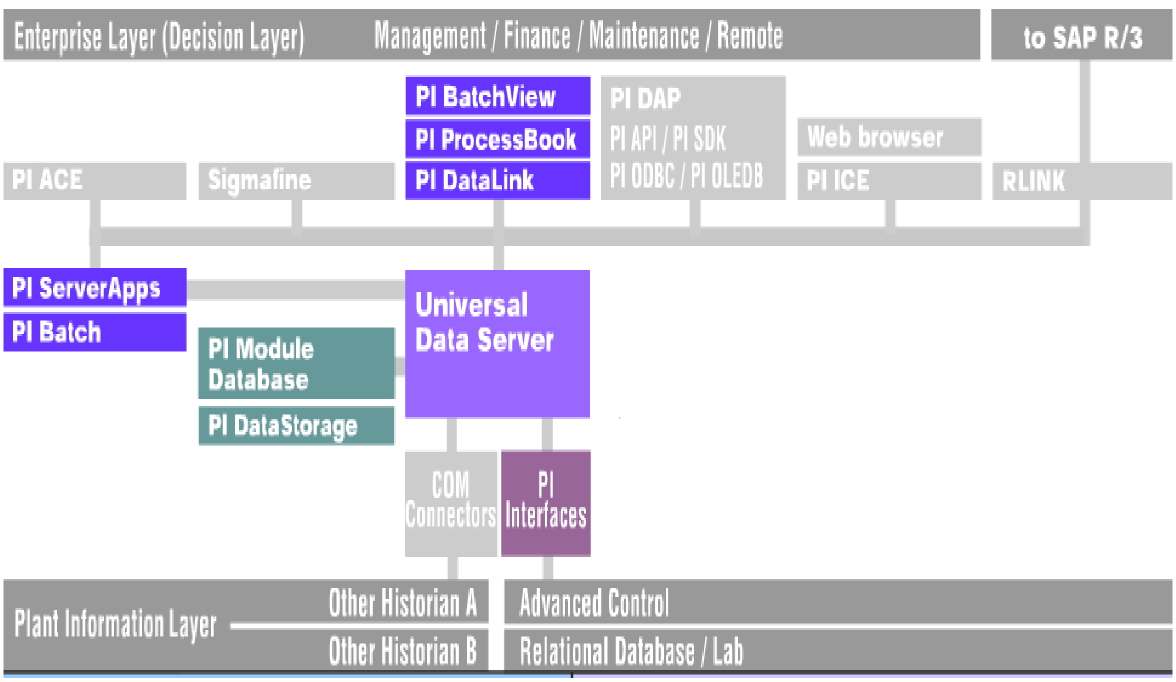

Figure 23 OSI PI-Based Architecture

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